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# A Dynamic Model of Contractor-Induced Delays in India

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**Abstract:** To understand delays in the Indian construction context, an exploratory survey was conducted as a precursor to the development of simulation models. System Dynamics (SD) was used to visualise the pivotal feedback relations that cause delays to evolve mechanisms that reduce it. A community development construction project in India serves as the case for modelling. Findings of the study suggest that definite causal feedback relations exist among difficulties in financing the project, ineffective planning and scheduling, poor communication and coordination by the contractor, conflict between the contractor and other stakeholders and use of inappropriate construction methods and construction delays. However, the modelling efforts reveal that the use of these best practices can reduce delay significantly: provision of adequate project finances and cash flow, effective planning and scheduling, adoption of appropriate construction methods and contingencies for rework in the schedule.

**Keywords:** Construction, Delay, Project, System dynamics, India

## BACKGROUND

Several construction management scholars say the reasons for delays in projects could be classified under broad issues related to clients, contractors, design, construction, materials, equipment and management (Alaghbari et al., 2007; Assaf and Al-Hejji 2006; Chan and Kumaraswamy, 1997; Desai and Bhatt, 2013; Odeh and Battaineh, 2002). However, out of these issues, contractor-related issues play a major role in causing delays in construction projects in developing countries (Doloi, 2009; Odeh and Battaineh, 2002; Sambasivan and Soon, 2007). Scholars have also argued that contractors form important parts of construction projects. They are essentially responsible for the actual construction activities on project sites and as such, challenges faced by contractors could cause significant delays in projects (Hwang, Zhao and Tan, 2015; Hwang and Yang, 2014; Hwang and Leong, 2013; Ndekugri, Braimah and Gameson, 2008; Olawale and Sun, 2010). According to recent studies in India by Aswathi and Thomas (2013), contractors, rather than consultants and owners, were the most responsible party for the delays in construction projects. Similarly, according to Doloi, Sawhney and Iyer (2012) and Doloi et al. (2012), more than 50% of Indian projects have both cost and time overruns and the major reasons are contractor-related issues, such as an inefficient contractors' lack of commitment and contractors' improper planning.

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A plethora of studies have observed contractor-related factors and various methods of analyses of construction delay across the globe. However, inquiries relating to the development of policy interventions to resolve the challenges of delay in construction projects in relations to contractor aspects are limited. Therefore, the objectives of the study were to delineate the influential contractor-related issues that lead to delays in India, to evolve the causal feedback relations among the contractor related issues and to develop a model to estimate the reduction of delay under varied strategic interventions.

The next section of the paper presents the reviewed literature by highlighting the factors of delays that are under the control of contractors. The research approach, which includes a survey and a modelling effort, follows the literature review section. The findings of the survey and the modelling efforts show the dynamics of the phenomenon and suggest policy implications to conclude the paper.

## LITERATURE REVIEW

The sources of construction delays are varied and to mention a few, they relate to the performance of project actors, the availability of resources, the schedule delay and the contractual relations (Alaghbari et al., 2007; Odeh and Battaineh, 2002; Pongpeng and Liston, 2003; Stumpf, 2000). In terms of causation by project actors, the clients, contractors, designers, subcontractors and suppliers could make decisions that lead to delay. Of these actors, contractors have major impacts in India (Aswathi and Thomas, 2013; Doloi, Sawhney and Iyer, 2012).

The major contractor-related factors that are observed to be responsible for delays are as follows: difficulties in financing project by contractor (Doloi, 2009); delays in financing projects by contractors (Sambasivan and Soon, 2007); rework due to errors during construction (Doloi, 2009); conflicts between contractor and other parties (consultant and owner) (Al-Kharashi and Skitmore, 2009); poor site management and supervision (Chan and Kumaraswamy, 1997; Satyanarayana and Iyer, 1996); poor communication and coordination by contractor with other parties (Ahsan and Gunawan, 2010; El-Razek, Bassioni and Mobarak, 2008; Lo, Fung and Tung, 2006); ineffective planning and scheduling by the contractor (Ahsan and Gunawan, 2010; El-Razek et al., 2008; Lo et al., 2006); improper construction methods implemented by contractors (Chan and Kumaraswamy, 1997; Satyanarayana and Iyer, 1996); delay in site mobilisation (Chan and Kumaraswamy, 1997; Satyanarayana and Iyer, 1996); and unavailability of incentives for contractor for finishing ahead of schedule (Aibinu and Odeyinka, 2006; Al-Kharashi and Skitmore, 2009).

It was, however, observed that although many of these factors have cause and effect relations (Assaf and Al-Hejji, 2006; Sambasivan and Soon, 2007), explicit studies relating to such feedback relations and their influence on construction delay are limited.

## RESEARCH METHODS

The study used a survey research method for the collection of primary data. Descriptive statistical analysis and Cronbach's alpha test were conducted to check the reliability and suitability of the data set. The survey research method was employed to collect primary data from the various stakeholders in construction projects in India. A total of 120 questionnaires were administered; 100 of which were returned (85% response rate). Project managers, architects, engineers, designers, skilled technicians, specialist consultants, quantity surveyors, contractors and owners were surveyed using a semi-structured method. Various construction projects from which respondents were selected for survey included buildings, roads, bridges, railways, power plants and industrial complex projects. The profile of the sample and the projects is presented in Table 1.

Table 1. Profile of Respondents

| **Project Characteristics** | | | **Characteristics of Respondents** | | |
|---|---|---|---|---|---|
| **Type of Projects** | **Number** | **Percentage** | **Respondents** | **Number** | **Industry Time** |
| Buildings | 11 | 39.3 | Owners/Clients | 13 | 14–22 |
| Roads | 6 | 21.4 | Project managers | 17 | 8–15 |
| Bridges | 4 | 14.2 | Consultants | 12 | 7–18 |
| Railway | 2 | 7.2 | Architects | 11 | 6–15 |
| Power plants | 2 | 7.2 | Engineers | 14 | 13–20 |
| Industrial complexes | 3 | 10.7 | Contractors | 13 | 12–21 |
| Total | 28 | 100.0 | Estimators | 11 | 5–14 |
| | | | Skilled technicians | 9 | 4–16 |
| | | | Total | 100 | 8.6–17.6 |

To compile the survey questionnaire, the related literature was reviewed to identify the causes of contractor induced delay. Then, a set of major delay factors were compiled and checked for their relevance in India. A pilot survey was initially conducted among the project actors with a sample size of 20 by using a preliminary questionnaire to validate the selection of the factors to reflect the Indian construction industry. The questionnaire was modified and refined after the pilot survey based on the suggestions of the respondents and the refined questionnaire was then used for the survey for the data collection.

The respondents were asked to provide their opinions on the various parameters that cause delays and to rate the challenges on a scale of 1 to 5 from their experiences. A five point Likert scale (1 = Not influential, 2 = Less influential, 3 = Influential, 4 = Significantly influential and 5 = Most influential) was adopted for guiding the participants to provide their responses with varying degrees of influence of factors on construction delay.

A Likert scale was employed to measure the relative influence of the variables in terms of a delay index (DI) causing delay. The DI is the mean score achieved from the responses of the respondents. The DI was then used to develop conceptual models by using System Dynamics (SD) modelling principles (Sterman, 2000). A construction project was considered as the system for developing the model. The influential factors, which were their positive and negative influences on the related factors and the causal relationships among them, were used to develop the SD models. The causal relationships among the variables within and across the major parameters were developed based on the evidence observed from the literature, as well as discussions and experiences of the professionals surveyed. Then, a quantitative SD model was developed and simulated to compute the project duration and delay period under different scenarios and strategic interventions to reduce delay. While developing the models, discussions with the experts and professionals were conducted by using semi structured interviews (Day and Bobeva, 2005; Donohoe and Needham, 2009; Pandza, 2008). The discussions were conducted four times: (1) before developing the models to know the inter-linkage of parameters, (2) while developing the model to understand causal feedback relations, (3) to validate the causal feedback relations and conceptual models and (4) while simulating under different strategic interventions. Modifications and amendments to the causal relations and model development and interpretation were made after each stage of the discussion.

## MODELLING AND RESULTS

### Major Contractor Related Factors Influencing Construction Delay

Parameterisation is essential to identifying the major influential contractor-related factors, which significantly contribute to delay in Indian construction projects. This was performed through evaluation of the relative impact of the factors by using the Likert scale followed by discussion with the stakeholders. Table 2 presents the relative importance of the factors observed from the research. It was observed that difficulties in financing project by contractor, delays in financing project by contractor, reworks due to errors during construction, conflicts between contractor and other parties (consultant and owner) and finally, ineffective planning and scheduling of project by contractor were all perceived to be significantly influential in terms of construction delay. Additionally, poor communication and coordination by contractor with other parties, improper construction methods implemented by contractor and delay in site mobilisation were considered influential. However, the lack of inceptives for contractors to finish ahead of schedule does not appear to be influential. The findings, more or less, corroborate the findings of the other scholars in the literature.

Table 2. Significance of Various Contractor Related Factors Influencing Delay in Construction

| Factors | Delay Index (DI) | SD | Cronbach's Alpha | Rank |
|---|---|---|---|---|
| Difficulties in financing project by contractor | 4.25 | 0.36 | 0.93 | 1 |
| Delay in financing project by contractor | 4.15 | 0.38 | | 2 |
| Rework due to errors during construction | 4.10 | 0.32 | | 3 |
| Ineffective planning and scheduling of project by contractor | 3.90 | 0.33 | | 4 |
| Conflicts between contractor and other parties (consultant and owner) | 3.70 | 0.28 | | 5 |
| Improper construction methods implemented by contractor | 3.65 | 0.26 | | 6 |
| Poor communication and coordination by contractor with other parties | 3.65 | 0.31 | | 7 |
| Delay in site mobilisation | 3.60 | 0.34 | | 8 |
| Poor site management and supervision by contractor | 3.20 | 0.28 | | 9 |
| Unavailability of incentives for contractor for finishing ahead of schedule | 2.85 | 0.26 | | 10 |

*Note:* External factors such as the weather condition have not been considered as they are beyond the control of project management

## System Dynamics Modelling

### SD modelling and justification of its application

A number of techniques have been developed to understand delay in the construction industry (Braimah, 2013). For instance, Paleneeswaran and Kumaraswamy (2008) developed an integrated decision support system (DAS) for delay analysis in construction projects and Terry (2003) used network causal mapping and an SD approach to study the impact of delays on a project. Some of the reviewed literature used Monte Carlo simulation to derive delay reduction interventions (Aswathi and Thomas, 2013) and fuzzy logic for delay computations (Pandey et al. 2012). However, many of these methods do not explicitly consider the causal feedback relationships among the factors that cause delay, specifically with regards to contractor-related factors. The research was able to bridge this gap with SD modelling.

SD is a modelling technique in construction project management for improving the effectiveness of the decision-making process (Han et al., 2013;

Lyneis and Ford, 2007). The use of SD is not limited to projects as the unit of analysis. According to SD modelling scholars, this approach has the potential to contribute to decision-making in a complex system, in which interconnectivity and complicated feedback processes are rife. Given that the SD model could handle interconnectivities arising from complicated feedback processes, it is argued that it can help understand the inter-related factors at play in the industry and assist in developing plausible policy interventions to resolve the delay in construction projects. Under this premise, SD modelling is used to resolve delays at a particular attribute level – the contractor level.

**Conceptualisation of the model**

As evident in Table 2, difficulties in financing a project by a contractor, delay in financing project by a contractor, conflicts between a contractor and other parties (consultant and owner), rework due to errors during construction and ineffective planning and scheduling of project by a contractor are the major contractor-related causes of a delay. The influence of poor communication and coordination by a contractor with other parties, improper construction methods and a delay in site mobilisation are, however, not significant. The causal relations among these contractor-related factors that cause delay are presented in Table 3. The causal feedback relationships among the factors and a delay in the SD model (Figure 1) reveal that ineffective planning and scheduling has a direct linkage with construction delay through a feedback mechanism (balancing loop CB1). Ineffective planning, essentially, can happen because of poor communication. It can influence the construction activities through delay in site mobilisation influenced by poor management of site and supervision and cause delay that disrupts the effectiveness of the planning by feedback mechanism (CB1A). Similarly, difficulty in financing the project by a contractor, which can lead to a delay in financing the project, will cause a construction delay. Conversely, once a delay occurs, the contractor will face difficulty in financing the project because of factors such as cost escalation and the mobilisation of funds. Thus, difficulty in financing the project causes delay and disrupts the project through feedback mechanism (balancing loop CB2). Additionally, delay can happen because of rework if appropriate provisions are not in the planning and schedule of the project. However, the adoption of best practices of the industry, such as planning for financing and budgeting ahead of time, provision of good communication and coordination, use of appropriate construction methods and provision for rework and exigencies can reduce delay through the four reinforcing feedback mechanisms with delay as envisaged in the Figure 1. First, planning for finances and budgeting ahead of time can lessen the burden of difficulty in financing; as a result, the project will not be slowed down or disrupted because of lack of finance, thus reducing delay. As delay is reduced or avoided, the project will remain within the budget. This implies that planning for finance and budget ahead of time will reduce delay and vice versa through reinforcing feedback mechanism CR1A. Second, the provision of good communication and coordination can reduce ineffective planning and scheduling and consequently delay through the reinforcing mechanism CR1B. Moreover, it will also assist in proper site management and supervision and reduction in delay in site mobilisation, which, in effect, will reduce the negative effect of the disrupting mechanism CB1A. Third, rework needs to be considered as an essential element in the construction process. Therefore, provision for rework and exigencies in the schedule can lessen the ineffectiveness of the planning and secluding, thereby avoiding any undue impedance in the project through the mechanism CR1C. Fourth, if rework is necessitated by poor quality of work or use of inappropriate construction methods, then rework can be reduced by adopting appropriate construction methods through feedback mechanism CR1D, which in effect reduce delay in construction.

Therefore, it is envisaged that reduction of delay will occur through the actions of the reinforcing loop CR1 (constituting reinforcing sub loops CR1A, CR1B, CR1C and CR1D) between the adoption of best practices and construction delay. Thus, the disruptive mechanisms through CB1 and CB2 can be balanced or negated by reinforcing mechanism CR1. Therefore, causal feedback mechanisms, which involve effective planning and scheduling, planning for finance and budget ahead, adoption of construction methods, contingencies in planning for rework and exigencies by the contractor and construction delay, are the dynamic hypothesis; these should be considered while developing policy interventions to reduce delay in construction.

Table 3. Cause and Effect Relationship among Contractor Related Factors

| Cause | | Effect | +/– | Source |
|---|---|---|---|---|
| Difficulties in financing project by contractor | → | Delay in financing project by contractor | + | Doloi (2009); Odeh and Battaineh (2002); Sambasivan and Soon (2007); Satyanarayana and Iyer (1996) |
| Delay in financing project by contractor | → | Delay in construction | | |
| Poor communication and coordination by contractor with other parties | → | Conflicts between contractor and other parties (consultant and owner) | + | Ahsan and Gunawan (2010); Assaf, Al-Khalil and Al-Hazmi (1995); El-Razek et al. (2008); Lo et al. (2006) |
| Conflicts between contractor and other parties (consultant and owner) | → | Delay in financing project by contractor | + | Al-Khalil and Al-Ghafly (1999); Al-Kharashi and Skitmore (2009); Doloi (2009) |
| Improper construction methods | → | Rework due to error during construction | + | Chan and Kumaraswamy (1997); Satyanarayana and Iyer (1996) |

(continued on next page)

Table 3. (*continued*)

| Cause | | Effect | +/– | Source |
|---|---|---|---|---|
| Poor communication and coordination by contractor with other parties | → | Ineffective planning and scheduling of project by contractor | + | Aibinu and Odeyinka, (2006); Ahsan and Gunawan (2010); Assaf, Al-Khalil and Al-Hazmi (1995); El-Razek et al. (2008); Lo et al. (2006); Semple, Hartman and Jergeas (1994); |
| Rework due to errors during construction | → | | | Chan and Kumaraswamy (1997); Doloi (2009a); Doloi et al. (2012); Satyanarayana and Iyer (1996) |
| Delay in site mobilisation | → | | | |
| Poor site management and supervision by contractor | → | Delay in site mobilisation | + | Chan and Kumaraswamy (1997); Satyanarayana and Iyer (1996) |
| Ineffective planning and scheduling of project by contractor | → | Delay in construction | + | Ahsan and Gunawan (2010); Assaf, Al-Khalil and Al-Hazmi (1995); BIS (2013); Doloi (2009a); El-Razek et al. (2008); Lo, Fung and Tung (2006) |
| Adopting best practices | → | Planning for adequate budget | + | BIS (2013) |
| Delay in construction | → | Difficulty in financing the project by contractor | – | |
| Adopting best practices | → | Effective communication and coordination | + | |
| Effective communication and coordination | → | Ineffective planning and scheduling by contractor | – | Doloi (2009); Doloi et al. (2012b); Sambasivan and Soon (2007) |
| Adopting best practices | → | Provision for rework in scheduling and planning | + | BIS (2013) |
| Provision for rework in scheduling and planning | → | Rework due to errors in construction | – | Doloi (2009); Doloi et al. (2012b); Sambasivan and Soon (2007) |

(*continued on next page*)

Table 3. (*continued*)

| **Cause** | | **Effect** | **+/–** | **Source** |
|---|---|---|---|---|
| Adopting best practices | → | Adoption of appropriate construction methods | + | BIS (2013) |
| Adoption of appropriate construction methods | → | Improper construction methods adopted by contractor | – | Doloi et al. (2012) |
| Reduction in improper construction methods adopted by contractor | → | Rework due to error during construction | – | Doloi et al. (2012) |

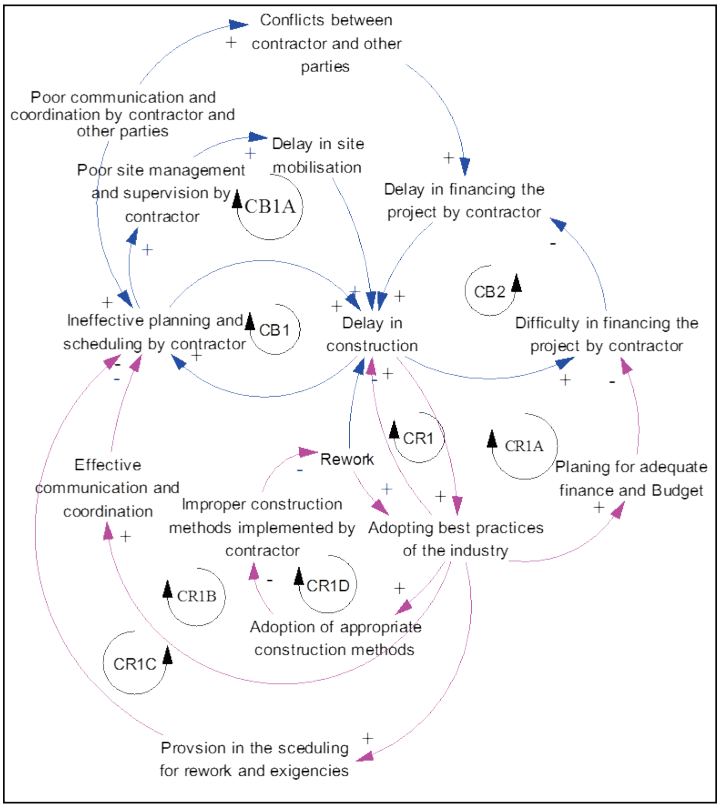



Figure 1. Conceptual SD Model of Contractor Related Factors Causing Delay in India

## Model building

Based on the previous explanations, a quantitative SD model was developed to observe the project duration and delay components in a construction project in India. Project duration is considered as a stock and there are three rate variables, which include normal construction rate (NCR), construction rate due to delay in financing and construction rate due to ineffective planning. Availability of finance, good communication, provision for rework and use of appropriate technology and construction methods are all the auxiliary variables, which influence the rate variables. Table 4 presents the various project attributes, project boundary and simulation variables used in developing and using the model. The maximum construction period of 36 months is considered as the model boundary and variables exogenous to the contractor-related factors in construction, which include client, consultant and design related factors are kept out of the modelling. The model was built by using STELLA software, which employed algorithms developed based on the inter-relationship and dependence of the variables. The major algorithms used in the model building are given in the Equation 1 to 4. For example, project period under a normal scenario is a function of initial project period and NCR (as shown in Equation 1); however, project period in future scenarios of delay is a function of the initial project period, normal construction rate, addition to project period due to (reduction in construction rate) finance delay, addition to project period due to (reduction in construction rate) ineffective planning, contribution to construction rate due to availability of finance, contribution to construction rate due to good communication, contribution to construction rate due to provision for rework in the schedule and contribution to construction rate due to use of appropriate technology and construction methods and their relative influences (as shown in Equation 2).

The simulation time unit considered was one month up to a maximum period of 36 months because the maximum duration of the project under pessimistic conditions was three years from the day of the project "start". In addition, a month was taken as the minimum time unit in simulation to easily comprehend the delay at different periods of construction. The Euler integration method with a time step of 0.03150 (for instance, in one month it integrates 1/0.03150 = 32 times) was used for simulating the model.

$$\text{Project period (t)} = \text{Project period (t–dt)} + \int_{t0}^{t} \text{Project period (t – dt)} * (\text{NCR} + \text{AFDCR} + \text{AIPCR} – \text{CAFCR} * \text{w1} – \text{CGCCR} * \text{w2} – \text{CRWCR} * \text{w3} – \text{CATCR} * \text{CATCR} * \text{w4}) * dt \qquad \text{Eq. 1}$$

$$\text{Project period normal scenario (t)} = \text{Project period (t–dt)} + \int_{t0}^{t} \text{Project period (normal scenario)} \qquad \text{Eq. 2}$$

Delay normal scenario ($D_{tn}$) = [Project period (t) – Project period normal scenario]/ Project period normal scenario Eq. 3

Delay original estimate scenario ($D_{te}$) = [Project period (t) – Project period original estimate]/ Project period original estimate Eq. 4

where,
NCR = Normal construction rate,
AFDCR = Addition to project period due to (reduction in construction rate) finance delay,
AIPCR = Addition to project period due to (reduction in construction rate) ineffective planning,
CAFCR = Contribution to construction rate due to availability of finance,
CGCCR = Contribution to construction rate due to good communication,
CRWCR = Contribution to construction rate due to provision for rework in the schedule,
CATCR = Contribution to construction rate due to use of appropriate technology and construction methods,
w1, w2, w3, w4 are the weightages given to the respective variables as observed from historical data and expert discussion for sensitivity analysis.

Table 4. Project Variables and Simulated Scenarios

| **Project Variables** | **Variable Attributes/Values** | **Remarks** |
|---|---|---|
| Type of project | Community development (building) | Type of building: A school cum disaster management community shelter<br>Location: Khurda district of Odisha state |
| Size of project | Two storeyed and approximately 800 sq. m. | |
| Type of structure | Framed structure, isolated footing foundation, Flat RCC roof | |
| Maximum project period | 3 years (36 months) | |
| Units of construction duration considered | In days | |
| Initial estimated construction duration | 300 days | |
| Construction rate factions | | |
| Normal rate of construction | 0.0033 units/day | Obtained from the stakeholders discussion and historical data of projects |

(continued on next page)

Table 4. (*continued*)

| **Project Variables** | | **Variable Attributes/Values** | **Remarks** |
|---|---|---|---|
| Initial effective communication fraction<br>Initial rework factor fraction<br>Initial financing factor fraction | | 0.0.10<br>0.0016<br>0.0011<br>0.10 | Obtained from Historical data of projects and discussion with engineering project execution personnel |
| w1 | | 0.25–1.0 | Based on experts and stakeholders discussion |
| w2 | | 0.1–0.75 | |
| w3 | | 0.1–0.5 | |
| w4 | | 0.1–0.5 | |
| | | **Simulated Scenarios** | |
| **Scenarios** | | **Simulation Variables** | **Combined Effects Considered** |
| Normal scenario | S1 | Business as usual (normal rate of construction as envisaged during project planning) | |
| Scenarios causing delay | S2 | Non-availability of finance | Difficulty in financing and delay in financing |
| | S3 | Ineffective planning | Lack of effective communication and inadequate scheduling |
| | S4 | Combination of ineffective planning and unavailability of finance | |
| Scenarios of reduction of delay under policy interventions | S5 | Good communication | Good communication leads to effective planning |
| | S6 | Good communication and availability of finance | |
| | S7 | Good communication, availability of finance, provision for rework | |
| | S8 | Good communication, availability of finance, provision of rework and use of appropriate technology in construction | |

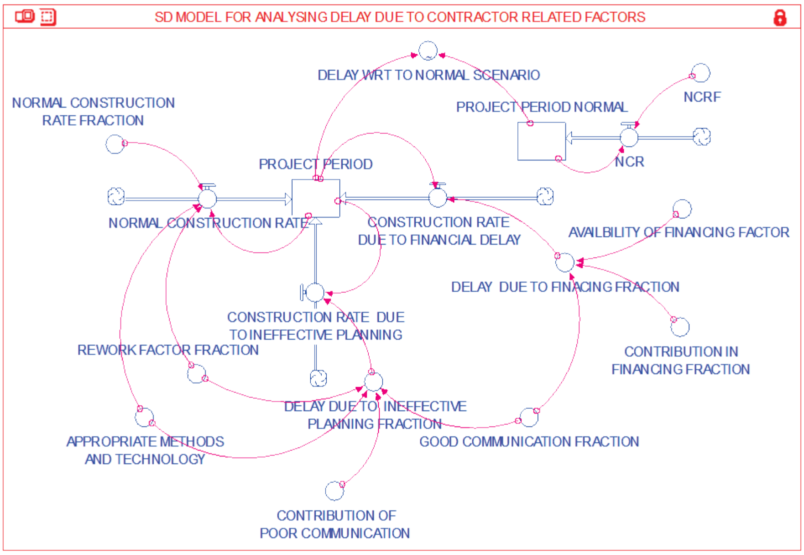
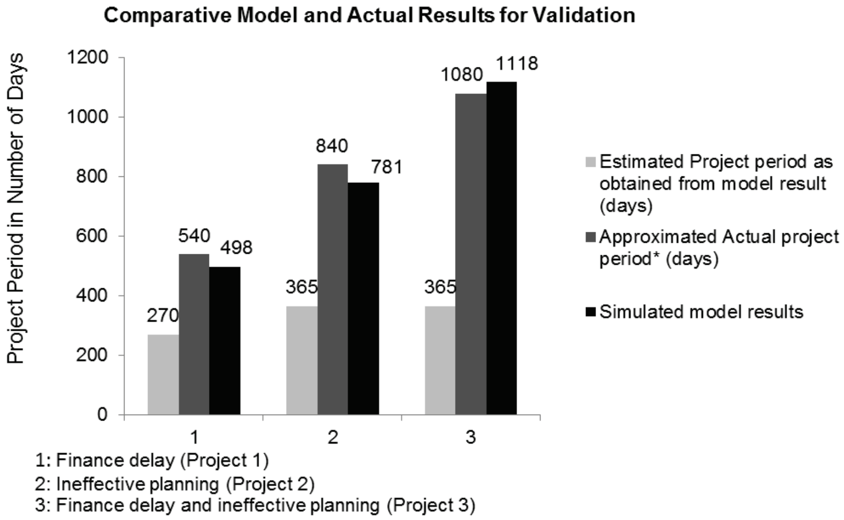



Figure 2. SD Model (Stock Flow Diagram) Based on Analysing Delay Due to Contractor Related Factors in Construction Projects

## Model validation

Once the model was established and before it was used for simulation, it was tested to check if sufficient confidence in the model is attained. For this purpose, a structure verification test, an algorithm check and a behavioural validity test were each conducted. A structure verification and an algorithm check were conducted by checking the causal feedback relationships and correctness of mathematical equations. For behavioural veracity of the model, the model was simulated for three completed projects, having similar attributes in the same location and the results obtained from simulations of the model were compared. The compared results (Figure 3) revealed that the model results vary marginally (from 3.5% to 7.8%), while showing the behavioural validity of the model. In addition, experts were consulted to make adjustments and fine tune the model. The adjustments and fine tunings were performed by adjusting the variable weights, checking the causal effects, verifying the influence of rates and results of auxiliary variables and the behaviour of the model to provide results of measured variables, such as project duration under different simulated conditions that should be close to real life scenarios (comparable to other similar projects).The validated model was simulated to compute the project period under different simulated scenarios.




*Source:* Projects are sourced from Odapada and Balipatna blocks in Odisha, India (2009–2013)

Figure 3. Comparison between Model Results and Actual for Validation of the Model

**Insights from the Simulated SD Models**

The project duration and delay in construction project as obtained from the SD model was analysed under four categories: (1) normal scenario (business as usual), (2) project period under important factors causing delay scenarios, (3) project duration under strategic interventions to reduce delay and (4) comparative project duration under different scenarios. Figure 4 presents the project period and the trend of the delay under the scenarios, which cause delay. In this case, two important scenarios are presented: difficulty in financing the project with the contractor (which includes delay in financing, difficulty in obtaining the finance, budgeting and lack of communication among the stakeholders responsible for financing) and ineffective planning (which is a cause of lack of effective communication) are considered (Table 4). It was observed that under normal scenarios, the maximum project duration will rise to a maximum of 12.7% from the original estimate, which is quite marginal. However, the project period will be fairly high under the scenarios of finance delay (84.3%) and ineffective planning (114%). It is also clear that under the scenario of the combined effect of financial delays and ineffective planning, the delay in the project will be the worst. The project period under such a scenario will be exceeded by 206.3% from the originally estimated duration. Hence, the simulated scenarios show that while difficulty in financing the project and ineffective planning autonomously will cause significant delay in the construction project, the combined effect is much worse. Therefore, policy interventions are needed to avoid such scenarios.

Figure 5 presents the project period and project behaviour under different strategic policy interventions. The simulations were conducted under the four most significant scenarios as mentioned in Table 4. The scenarios that did not have significant impact, either independently or in combination, have been ignored for the simplicity of the analysis. While developing scenarios under different policy interventions, comparisons were made with the worst-case scenarios, as well as with the normal and original project duration. It was found that if good communication is affected, which essentially assists in obtaining effective planning, the project period will be reduced from the worst-case scenarios of combined scenarios caused by ineffective planning and unavailability of finance, although it is still much higher than both original and normal scenario project periods. This shows that policy interventions that are based on the combination of good communication and the availability of finance alone will not reduce delays appreciably, although it will limit the delay to the certain extent. Under a combined scenario of good communication, the availability of finance, provision for rework and appropriate use of technology and construction methods, the project period will be significantly reduced, i.e., it will be reduced by 59.8%, from the worst-case scenario. In other words, the project period will be marginally higher (23%) than the original project period and close to (exceeds only by 9.2%) the project period under a normal scenario.

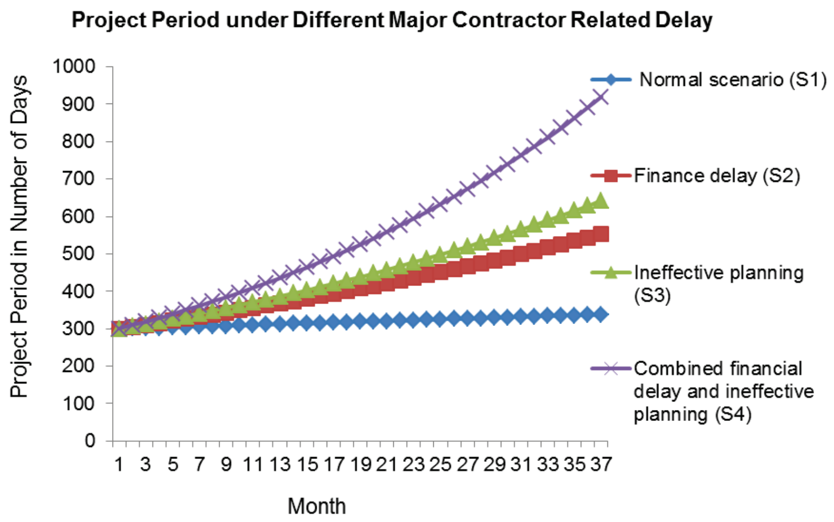



Figure 4. Project Duration under Different Scenarios Causing Delay

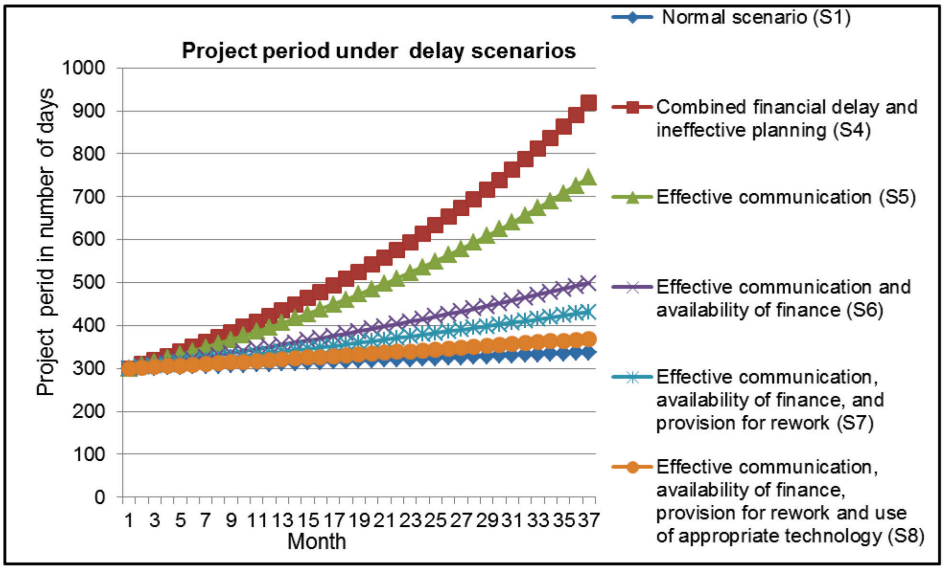



Figure 5. Project Duration under Different Scenarios of Policy Interventions to Reduce Delay

## CONCLUSIONS

This study addressed the various contractor-related factors that are influencing project delays in construction. To achieve the aim of this research, SD models were used to comprehend the amount of delay that can eventuate in a project when individual or a combination of contractor-related issues are at play in a project. Before the SD models were developed, an evaluation was conducted based on an index developed with an exploratory survey in India. The simulated models revealed that delays that manifest through gaps in finance and project planning would substantially impact the timely delivery of projects. This realization, therefore, requires the use of policy interventions that could handle planning and finance issues in construction.

There are three policy implications that are generated from the findings of the study. First, planning ahead for finance can lessen the burden of difficulty in financing so that the project will not be slowed down or disrupted because of a lack of funding. Moreover, the reduction of delay will enable the project to remain within the budget, which implies that planning for finance ahead of time will reduce a delay and vice versa. Second, provision of good communication and coordination is essential as this could schedule clashes that contribute to delays. It will also aid in proper site mobilisation, management and supervision. Third, the adoption of appropriate construction methods can reduce rework if produced by poor quality of work or use of inappropriate construction methods, which would, in effect, reduce a delay in construction. In particular, the combination of these policies in a project would reduce a delay to a significant extent.

The paper has its limitations. Although, project actors were surveyed in India, the modelling effort only used a single project to provide insights into the dynamics of delays due to contractor-related matters. However, it is envisaged that the findings of the research should assist project actors (most especially contractors) to diagnose delay challenges and evolve mechanisms to address them on their projects. Additionally, the research offers a methodology to understanding the influence of various contractor-related factors that cause delay in a project. The quantification of the extent of influences of these factors on projects amplifies the need to address them.

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